

An initial study to investigate generating hydrocarbon potential of Tertiary Coals from Balikpapan and Pulaubalang Formations in Lower Kutai Basin, East Kalimantan, Indonesia

M Dwiantoro^{1*} and Sundoyo¹

¹Faculty of Technological Sciences, Mining Engineering Department, Kutai Kartanegara University, Tenggarong, East Kalimantan, Indonesia

*corresponding author: mulyonodwiantoro@gmail.com

Abstract. Seven representatives of Middle to Late Miocene coal samples from two important different sediments of coal-bearing succession, Balikpapan and Pulaubalang Formations from Embalut Coalfield in Lower Kutai Basin, were subjected to a detailed organic geochemical method for Total Organic Carbon and Rock-Eval pyrolysis. The aim of the present research study is to evaluate preserved organic matter for quantity, quality, thermal maturity, and to recognize depositional environment. Organic geochemistry results, reported in this study, were interpreted to indicate organic material for hydrocarbon potential of the coal seams. Even though these results are only an initial study, but they can be used as a significant reference for upcoming research in exploring the future of renewable energy.

Keywords: Hydrocarbon potential, Lower Kutai Basin, organic geochemistry

1. Introduction

Over the last few decades, one of the famed organic geochemical methods that have been most frequently performed by numerous researchers in the laboratory to investigate the bulk of hydrocarbon generation from coals is an open-system pyrolysis. To perform this pyrolysis experiment, it requires organic geochemical device named Rock-Eval Analyzer which has been widely applied to identify the gas and oil generation of source rocks from various basins all over the world (1)(2)(3)(4)(5). In this pyrolysis system, the generation product formed during this pyrolysis system over a temperature range 250-550°C is called a bulk of hydrocarbon. Bulk here means the undetectable of each component of the hydrocarbon element of the pyrolyzed source rocks. Thus, it suggests that Rock-Eval pyrolysis can be considered as an early screening tool to investigate the bulk hydrocarbon potentials of source rocks in this study area. But, to find out more detail about the generation potential of each element of hydrocarbon in a source rock, Gas Chromatography-Mass Spectrometry (GC-MS) and Pyrolysis Gas Chromatography (Py-GC) can be applied (6)(7)(8).

Numerous studies of bulk hydrocarbon potential and kerogen type of coals from Kutai basins have been carried out by previous researchers in the last decade (9)(10)(11). These publications stated that coals from Kutai Basin have considerable of hydrocarbon generating potential especially for methane gas (12)(13) even though its development as non-conventional energy has not been commenced yet in



this basin. Regardless of this condition, the current research is expected with carefully to assess and compares the characters of hydrocarbon generating potential, thermal maturity, kerogen type, and depositional environment of coals from two different important formations of coal-bearing succession namely Pulubalang and Balikpapan. Then, it can be utilized as a substantial reference for the upcoming research of renewable energy source in this study area. To ascertain more detail about methods, procedures, and research results can be observed in the following paragraphs.

2. Site Location and Geological Setting

The site location is situated at an active open-pit coal mine from Embalut Coalfield (Figure 1) in the central portion of Kutai Basin that contains Middle to Late Miocene bituminous coal-bearing sediments that exhibit marked variations of depositional environments, thermal maturities, and thickness. Based on geological evolution, this study area is one of an enormous sedimentary basin in eastern Indonesia that underwent of subsidence effects and then followed by sedimentation processed at the beginning of the Early Tertiary period. This area is well known as East Kalimantan Basin (14)(15). Then, the subsequent significant tectonics happened in this basin during Miocene to Eocene period were uplift and inversion which then divided the basin into three part of sub-basin, e.g., Tarakan Basin in the north side, Kutai Basin in the central position, and Barito Basin in the south side. The Kutai Basin itself was divided into two sub-basins namely Upper Kutai Basin and Lower Kutai Basin where the sedimentation direction starts from Kuching Heights in the west side toward to the east side as a result of extension linked to the opening of the Makassar Straits(16)(17)(18).

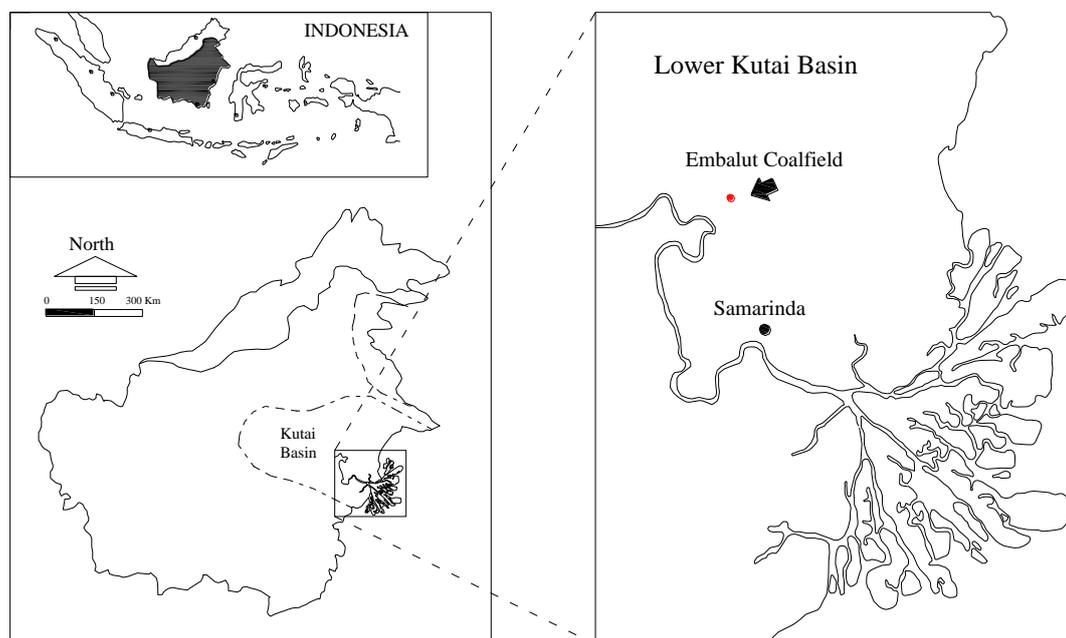


Figure 1. The site location map of the Embalut Coalfield in Lower Kutai Basin.

The Upper Kutai Basin is an area that experienced uplift and inversion during Early Miocene from Paleogene's depocenter then eroded subsequently(16). The uplifting on the west side of this basin and the sea-floor spreading of Makassar Strait was responsible for the deposition of sediments in the east side of the basin which became very thick, deep, and asymmetry of fold-system. To date, the asymmetric fold-system can be seen in the present geological condition extending from the center to the east side of Lower Kutai Basin. It is well known as a mega-folding structure of Samarinda Anticlinorium with the presence of major strike-slip fault system (14)(15)(18)(19). The deposited coals and generated hydrocarbon potential resources in Lower Kutai Basin are more prominent for

industrial demand and available for unconventional energy in the upcoming years than the Upper Kutai Basin. Generally, the most important coal producing formations in Lower Kutai Basin are dominated by Pulubalang and Balikpapan. Both of formations had abundant of coal deposits with various dimensions and qualities formed during the transition of transgression to regression phase of the deltaic environment in the Middle to Late Miocene period. The Tertiary stratigraphy sequences of Lower Kutai Basin consist of several significant coal-bearing formations which can be observed in Figure 2.

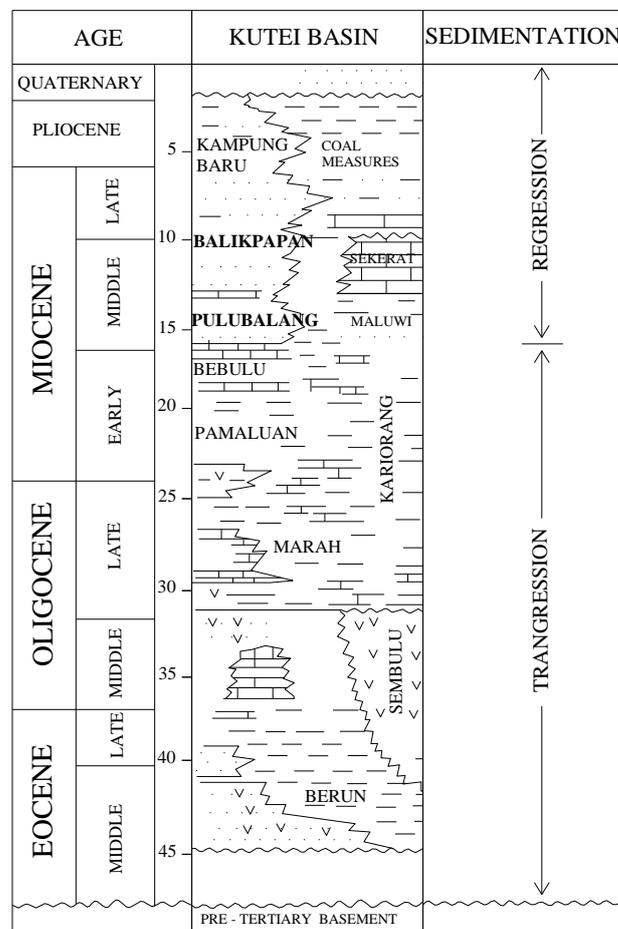


Figure 2. Generalized sequence stratigraphy illustrating the Kutai Basin succession(14).

3. Material and Methods

For simulation of gas generation from source rocks in a natural setting, pyrolysis experiment in the laboratory is extremely important. It is necessary to assess the hydrocarbon potential, predict thermal maturity behavior, quantity, and quality of organic matter in source rock. In this study, the outcrop coal samples were subjected to total organic carbon (TOC) content determination and Rock-Eval 5 pyrolysis to gauge their organic carbon richness and hydrocarbon generating potential. TOC content analysis of coal samples was determined by combustion in LECO RC-412 Carbon Analyser. The whole rock samples (<20 mg) were heated over a temperature range of 400°C to 950°C. The results were reported as weight percent of total weight of the sample. Rock-Eval pyrolysis was performed using the Rock-Eval 5 series. All techniques were performed at Geoservices laboratory in Jakarta, Indonesia. The Rock-Eval device was equipped with two ovens for pyrolysis and combustion processes, respectively. The hydrocarbon generated during a Rock-Eval analysis was monitored by

flame ionization detector (FID) whereas the non-hydrocarbon compound like CO₂ and CO released during pyrolysis and oxidation stages were monitored by an infra-red detector (FIR)(20).

A total of seven coal samples (Figure 3), comprising four coal samples from Balikpapan Formation (E1 to E4) and three coal samples from Pulubalang Formation (E5 to E7), were pulverized and analyzed for bulk rock method. Thus S1, S2, S3, and TOC values were obtained. S1, S2, and S3 are pyrogram curves generated during pyrolysis. S1 is the amount of hydrocarbon released during thermal cracking of kerogen (mg HC/g rock) in rock spore space at 300°C.

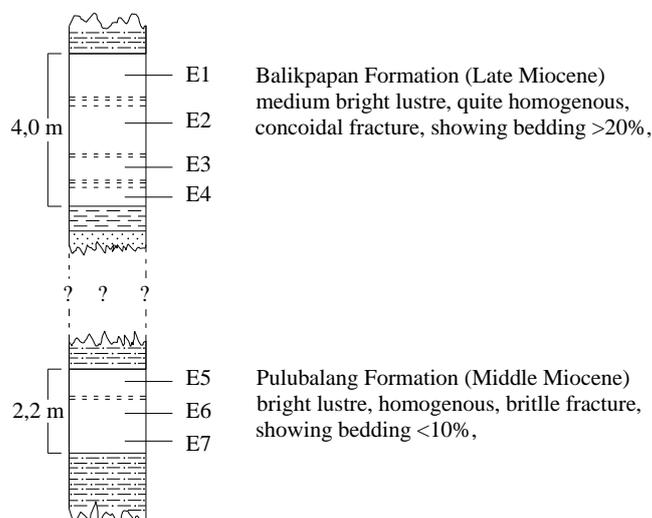


Figure 3. Vertical profile the distribution of seven selected coal samples and their lithotype characters.

The peak of S2 is the amount of hydrocarbon released during thermal cracking of organic matter (mg HC/g rock) and heavy hydrocarbons at 300-650°C at the heating rate 25°C/min (temperature-programmed pyrolysis). The temperature complying with the maximum amount generated hydrocarbons S2 is termed T_{max}. S3 is the CO₂ amount formed as a result of the decomposition of carboxyl groups and other oxygen-containing kerogen compounds at 300-400°C (mg CO₂/g rock). Total Organic Carbon (TOC) and mineral carbon content were determined by the oxidation of organic matter after pyrolysis at 950°C in the air. Two others obtained values are Hydrogen Index (HI) and Oxygen Index (OI). HI is defined as the ratio S2/TOC and represents the quantity of pyrosable organic compounds from S2 relative to TOC in the samples (mg HC/g TOC). OI is defined as the ration S3/TOC and corresponds to the quantity of CO₂ from S3 relative to TOC (mg HC/g TOC). Production index (PI) showed the level of thermal maturation, $PI = S1 / (S1 + S2)$.

4. Result and Discussion

The source potential of seven coal samples analyzed in this study was assessed using Rock-Eval pyrolysis and LECO carbon analyzer. The values of parameters obtained by these tools are given in Table 1. The literature reference values as criteria for determining hydrocarbon potential and kerogen type for immature source rock, as well as for organic matter maturity are listed in Table 2.

Table 1. The values of total organic carbon dan Rock-Eval parameters.

| No. | Formation | Sample ID | TOC | S1 | S2 | S3 | HI | OI | T _{Max} | PI |
|-----|------------|-----------|-------|------|--------|-------|-----|----|------------------|-------|
| 1 | Balikpapan | E1 | 49.89 | 0.61 | 103.69 | 10.30 | 208 | 21 | 412 | 0.006 |
| 2 | Balikpapan | E2 | 51.68 | 0.47 | 120.23 | 7.97 | 233 | 15 | 413 | 0.004 |
| 3 | Balikpapan | E3 | 52.42 | 0.46 | 139.84 | 8.15 | 267 | 16 | 415 | 0.003 |
| 4 | Balikpapan | E4 | 50.05 | 0.27 | 83.64 | 7.29 | 167 | 15 | 411 | 0.003 |
| 5 | Pulubalang | E5 | 59.69 | 0.15 | 155.78 | 3.90 | 261 | 7 | 416 | 0.001 |
| 6 | Pulubalang | E6 | 58.95 | 0.16 | 155.90 | 2.78 | 264 | 5 | 417 | 0.001 |
| 7 | Pulubalang | E7 | 60.90 | 0.15 | 152.85 | 4.12 | 251 | 7 | 419 | 0.001 |

E1: Embalut-1; TOC: total organic carbon (weight % of rock); S1: amount of free hydrocarbon thermally extracted at 300°C (mg HC/g rock); S2: amount of hydrocarbon produced from pyrolysis up to 550°C (mg HC/g rock); S3: amount of CO₂ released from organic matter at higher temperature (mg CO₂/g rock); HI: hydrogen index (mg HC/g TOC); OI: oxygen index (mg HC/g TOC); T_{max}: temperature corresponding to S2 peak maximum (°C); PI: production index S1/(S1+S2) (mg HC/g TOC).

Table 2. Guidelines for interpreting source rock quantity, quality, and maturity (21).

| Quantity | TOC | S1 (mg HC/g rock) | S2 (mg HC/g rock) |
|--------------|-------------------|-------------------------|----------------------|
| Poor | <0.5 | <0.5 | <2.5 |
| Fair | 0.5-1 | 0.5-1 | 2.5-5.0 |
| Good | 1-2 | 1-2 | 5-10 |
| Very Good | 2-4 | 2-4 | 10-20 |
| Excellent | >4 | >4 | >20 |
| Quality | HI mg HC/g TOC | S2/S3 (mg HC/g rock) | Kerogen Type |
| None | <50 | <1 | IV |
| Gas | 20-200 | 1-5 | III |
| Gas and Oil | 200-300 | 5-10 | II/III |
| Oil | 300-600 | 10-15 | II |
| Oil | >600 | >15 | I |
| Maturation | Rv (%) | T _{max} (°C) | TAI |
| Immature | 0.2-0.6 | <435 | 1.5-2.6 |
| Early Mature | 0.6-0.65 | 435-445 | 2.6-2.7 |
| Peak Mature | 0.65-0.9 | 445-450 | 2.7-2.9 |
| Late Mature | 0.9-1.35 | 450-470 | 2.9-3.3 |
| Post Mature | >11.35 | >470 | >3.3 |

4.1 Quantity of organic matter

The total organic carbon (TOC) content of Pulubalang Formation has an average value of 58.95 (wt. %) whilst Balikpapan Formation has a slightly low average value of 50.76 (wt.%). It indicates that Pulubalang Formation has a higher organic material richness than Balikpapan Formation (Figure 4a). These values of TOC are considered the excellent generative potential of hydrocarbon source rocks. The content of free hydrocarbon (S1) of both formations, indicate the amount of hydrocarbon present in the rock in a free or absorbed state, varying from 0.15 to 0.61 mg/g (average of 0.32 mg/g HC). All of the analyzed samples have low S1 values < 0.5 mg HC, which may suggest low thermal maturity of the organic matter.

The amount of hydrocarbon produced during pyrolysis at 550°C (S2) suggested for excellent immature source rock in most of the samples. Pulubalang Formation has a higher average value of 154.84 (mg HC/g rock) than Balikpapan Formation that has an average value of 111.85 (mg HC/g rock) (Figure 4b). It showed that Pulubalang Formation can produce more gas generation than

Balikpapan Formation. In addition, the high value of S2 from Pulubalang Formation directly related to the abundant of vitrinite contents and the high reflectance value as an indicator of the thermal maturity of coals (22). The presence of TOC values will contribute significant effect to S2 values. The high value of TOC content gives a high value of S2 directly. This indicated by the relationship between TOC and S2 contents that gave a strong coefficient correlation about $r=0.9$. However, there was an anomaly of TOC value on sample E4 that has lowest TOC value. Two presumptions raised here are the low supplied of organic material and the degraded organic material due to oxidation effects during coals formation.

The amount of CO₂ released from organic matter during pyrolysis at a higher temperature (S3) has risen upward to the younger formation (Figure 5b). It is predicted that there was a shifting of depositional environment between those formations. Balikpapan Formation has a high of Oxygen Index that suggested to have significant oxidation effects during its depositional. In addition, Balikpapan Formation was deposited in a deltaic environment which strongly controlled by regression facies of rising and descending of the sea water level.

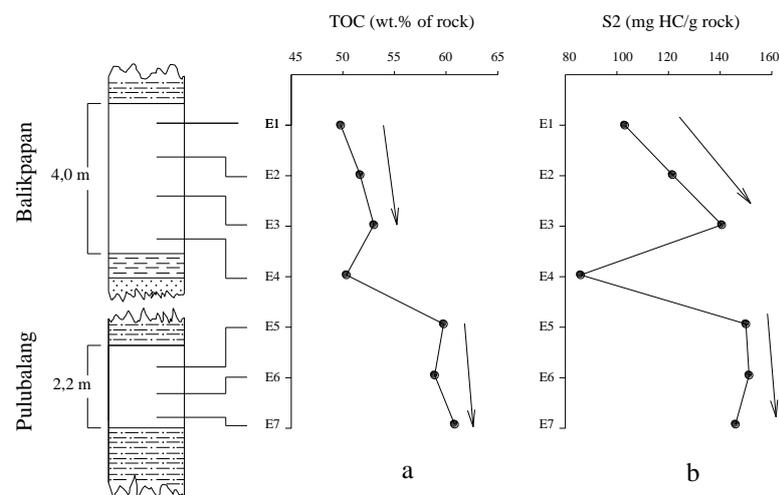


Figure 4. The vertical profile of TOC and S2 contents. It seems that Pulubalang Formation has a higher content value of those parameters than Balikpapan Formation.

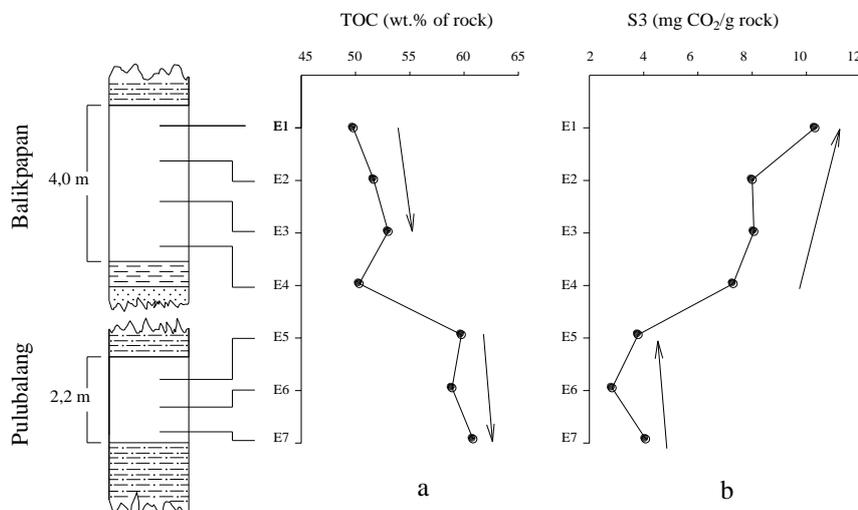


Figure 5. The vertical profile of TOC and S3 shows that coals from Balikpapan Formation have low of TOC contents that affected by oxidations during coals formation that marked by the high of S3 (CO₂) contents.

4.2 Quality of organic matter

Majority of analysed coal samples contain very good to excellent organic carbon richness and hydrocarbon generating potential. In order to give general indication of the quality of organic matter (kerogen type) in the samples, the plotting of Hydrogen index (HI) versus Oxygen index (OI) was applied. Values of Hydrogen Index (HI) and Oxygen Index (OI) indicate that majority of the analysed samples predominantly contains Type III kerogen (Figure 6). This type is commonly composed by terrestrial organic matter derived mainly from woody plant materials that is low in hydrogen contents and generates mainly gas. Based on the microscopic assessment that has been performed by previous researcher in the same location explained that the dominated maceral constituent derived in all coal samples is vitrinite (22).

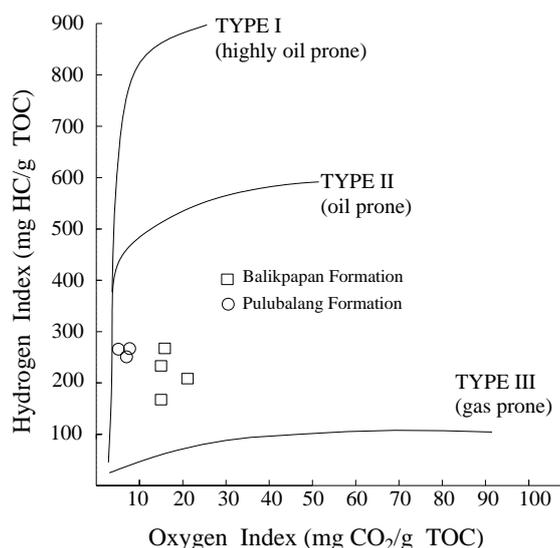


Figure 6. The plot of HI versus OI indicates that all samples are predominantly of Type III kerogen as a source of gas.

It is commonly accepted that samples with HI between 50 to 200 have the potential for hydrocarbon generation as gas prone source rock (21). Based on the HI values, reported in this study, suggest that the all samples contain mainly Type III organic matter which is capable of generating mainly gaseous hydrocarbons. The research result shows that Pulubalang Formation has a higher Hydrogen Index value than Balikpapan Formation. It indicates that oxidation influences during coal formation of this formation have inadequate effects. It seems that the Hydrogen Index value decreased relatively downward to the older formation (Figure 7b). Previous research, in the same site location, stated that this formation was formed in the transition from shallow marine to delta environment where the oxidation influence was relatively minor (22).

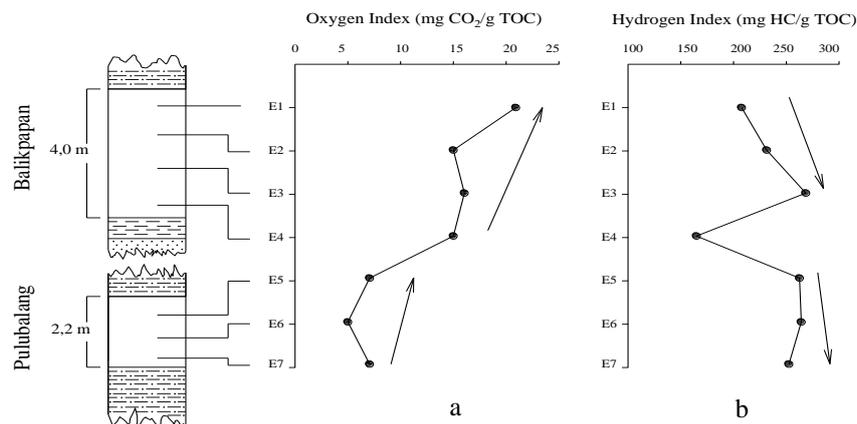


Figure 7. The vertical profile of OI and HI, a) OI content values significantly increased upward to the younger formation, b) conversely HI content values decreased downward to the older formation.

4.3 Maturity of organic matter

Production Index (PI) indicates the hydrocarbons amount that has been produced naturally, relative to the total amount of hydrocarbons which the sample can produce. Values of PI in range from 0.001 to 0.006 indicate an immature organic matter, confirming that low S1 values resulted from low thermal maturity. Furthermore, T_{max} values correspond to the temperature of the maximum generation of hydrocarbons during pyrolysis (S2 peak maximum). T_{max} ranges from 412 °C to 419 °C in analyzed samples, indicating immature stage, that may be affected by biological diagenesis processes. As predicted, the thermal maturity indicated by T_{max} value has an increased maturity downward to the older formation (Figure 8a). This results study also closely related to the previous research, based on reflectance vitrinite measurements, the maturity levels were in the immature stage of organic matter and they increased downward to Pulubalang Formation from R_{max} 0.37% to 0.55% (22). Increasing values of the thermal maturity of samples will provide the high values of S2 significantly. It is revealed by the relationship between T_{max} and S2 that showed a strong coefficient correlation about $r = 0.9$.

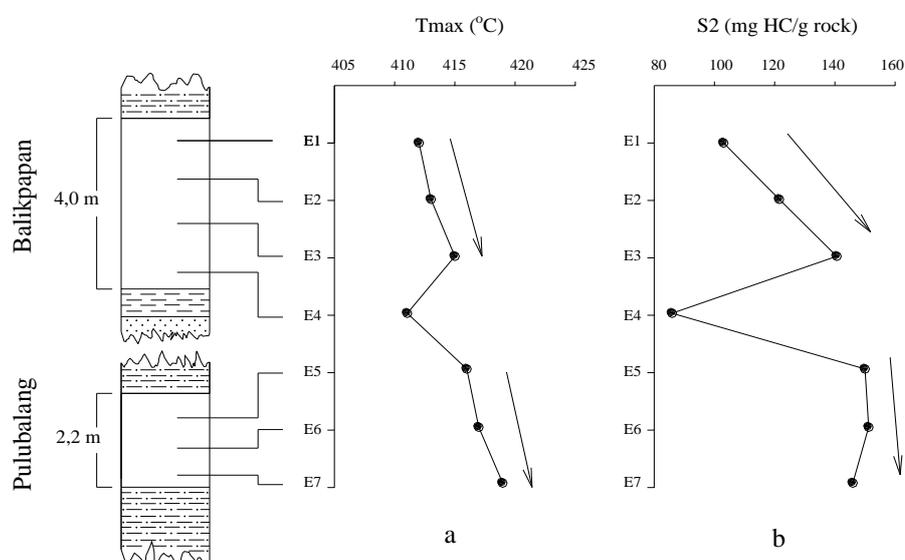


Figure 8. Vertical profile of T_{max} and S2 content increased downward to the older formation.

5. Conclusions

This paper presents an initial study of Middle to Late Miocene coal samples from two different formations and their characterization through organic geochemical methods (TOC and Rock-Eval pyrolysis). The research results revealed that all samples are immature source rock, have an excellent organic richness and includes in Type III kerogen as potential source rocks of hydrocarbon gas. Both formations have different characters of hydrocarbon potential in terms of generated gas during pyrolysis (S₂). They were greatly influenced by the transitional shifting depositional environment from transgression to regression phase that represented by Hydrogen Index and Oxygen Index content values. Basically, this study has provided significant information for upcoming research on unconventional energy resources assessment in Lower Kutai Basin.

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References

- [1] Tissot BP and Welte D H 1984 *Petroleum Formation and Occurrence* (Berlin: Springer-Verlag)
- [2] Horsfield B 1990 *Evaluating Kerogen Type According to Source Quality, Compositional Heterogeneity, and Thermal Lability* Review of Paleobotany and Palynology p 65(357-365)
- [3] Hadad YT and Abdullah WH 2015 *Hydrocarbon source rock generative potential of the Sudanese Red Sea basin* (Marine and Petroleum Geology) p 65(269-289)
- [4] Hazra B, Dutta S and Kumar S 2017 *TOC Calculation of Organic Matter Rich Sediments Using Rock-Eval Pyrolysis: Critical Consideration and Insight* (Intl. J. of Coal Geology) p 169(106-115)
- [5] Baioumy H, Ahmed A M A , Arifin M H , Anuar M N A and Musa A A 2018 *Geochemical Characteristics of The Paleogen-Neogen Coals and Black Shale from Malaysia: Implication for Their Origin and Hydrocarbon Potential* (J. of Natural Gas Science and Engineering) p 51(73-88)
- [6] Inan S 2000 *Gaseous Hydrocarbons Generated During Pyrolysis of Petroleum Source Rock Using Unconventional Grain-size: Implication for Natural Gas Composition* (Organic Geochemistry). 2000 p 31(1409-1418)
- [7] Widayat AH, van de Schootbrugge B , Oschmann W , Anggayana K and Puttmann W 2016 *Climatic Control on Primary Productivity Changes during Development of The Late Eocene Kiliran Jao Lake, Central Sumatra Basin, Indonesia* (Intl. J. of Coal Geology) P 165(133-141)
- [8] Wang S, Tang Y , Schobert H H , Jiang Y , Yang Z and Zhan X 2018 *Petrologic and Organic Geochemical Characteristics of Late Permian Bark Coal in Mingshan Coalmine, Southern China* (Marine and Petroleum Geology) P 93(205-2017)
- [9] Belkin EH, Tewalt S J , Hower J C , Stucker J D and O'Keefe J M K 2009 *Geochemistry and Petrology of Selected Coal Samples from Sumatra, Kalimantan, Sulawesi, and Papua, Indonesia* (Intl. J. of Coal Geology) p 77(260-268)
- [10] Anggayana K, Dwiantoro M and Widayat A H 2014 *Hydrocarbon Generation Potential of Indonesian Coals: from The Viewpoints of Organic Petrology and Geochemistry* (Japan:In CINEST)

- [11] Dwiantoro M 2016 *Optical Properties of Some Tertiary Coal from Kutai Basin Indonesia: Their Depositional Environments and Hydrocarbon Potential* (Geologi Pertambangan) p 2(26-36)
- [12] Moore TA, Bowe M and Nas C 2014 *High Heat Flow Effects on a Coalbed Methane Reservoir, East Kalimantan (Borneo), Indonesia* (Intl. J. of Coal Geology) p 131(7-31)
- [13] Bowe M and Moore T A 2015 *Coalbed Methane Potential and Current Realisation in Indonesia* (AAPG Memoir) p 90234(111-5)
- [14] Satyana AH, Nugroho D and Surantoko I 1999 *Tectonic Control on The Hydrocarbon Habitats of The Barito, Kutei, and Tarakan Basins, Eastern Kalimantan, Indonesia* (J. of Asian Earth Science)p 17(99-122)
- [15] Satyana AH 2013 *Gravity Tectonics in Indonesia: Petroleum Implication* (In Indonesian Petroleum Association) p 1-13
- [16] Calvert SJ 1999 *The Cenozoic evolution of The Larlang and Karama Basin, Sulawesi* (In Indonesian Petroleum Association) p 97-115.
- [17] Cloke IR, Milsom J and Blundell D J B 1999 *Implication of Gravity Data from East Kalimantan and The Makassar Straits, a Solution to The Origin of The Makassar Straits* (J. of Asian Earth Sciences) p 17(61-78)
- [18] Witts D, Davies L , Morley R J and Anderson L 2015 *Neogen Deformation of East Kalimantan: a Regional Perspective* (Jakarta: Indonesian Petroleum Association) p 22
- [19] Chambers JLC, Carter I , Cloke I R , Craaig J , Moss S J and Paterson D W 2004 *Thin Skinned and Thick Skinned Inversion Related Thrusting, a Structural Model for The Kutai Basin, Kalimantan, Indonesia* (AAPG Memoir) p 614-634
- [20] Behar F, Beaumont V , De B and Penteado H L 2001 *Rock-Eval Technology: Performances and Developments* (Oil & Gas Science and Technology) p 56(111-134)
- [21] Peters KE 1986 *Guidelines for Evaluating Petroleum Source Rock Using Programmed Pyrolysis* (AAPG Bulletin) p 318-329
- [22] Dwiantoro M, Sundoyo 2018 *Litotipe, Petrografi, dan Komposisi Kimia Batubara Formasi Pulubalang dan Balikpapan, Cekungan Kutai, Kalimantan Timur* (Jurnal Ilmu)Pengetahuan dan Teknologi Mineral (Universitas Mulawarman ISSN 2252-7605 p 6(1-10)